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EFFECT OF CELLULAR CONCRETE POWDER ON DURABILITY OF NORMAL STRENGTH CONCRETE

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Abstract

Present research program is dealing with the effects of cellular concrete powder (CCP) on the compressive strength and durability of concrete. CCP is an industrial by-product, which was applied as supplementary cementitious material (SCM) in the concrete mix. In the previous research of the authors of this paper, it was found that the cellular concrete powder, applied as an additive to the concrete mix, can increase the compressive strength and the resistance against freezing of concrete [1]. In that paper, the results were compared to a reference mix and a mix that contains air-entraining agent, which is a typical solution to increase concrete durability. Increasing of durability can be achieved by the application of supplementary materials, like silica-fume or metakaolin. Present paper is dealing with the comparison of concrete with metakaolin and cellular concrete powder, on the basis of compressive strength and frost resistance, using them as a cement substituting material. Different amount of metakaolin and CCP were added to the concrete mix, by substituting a given percentage (3, 10 or 17%) of cement with them. The results show the positive effect of both supplementary materials and based on present research the maximum amount of useful CCP can be approximated for the given concrete mix.

Streszczenie

Przedstawiony program badawczy dotyczy wpływu sproszkowanego betonu komórkowego (CCP) na wytrzymałość betonu na ściskanie i jego trwałość. CCP jest przemysłowym produktem ubocznym, który został zastosowany jako dodatek do cementu w mieszance betonowej. W poprzednich badaniach autorów tego artykułu stwierdzono, że sproszkowany beton komórkowy, stosowany jako dodatek do mieszanki betonowej, może zwiększać wytrzymałość na ściskanie i odporność na zamarzanie betonu [1]. W tym artykule porównano wyniki z mieszanką referencyjną i mieszanką zawierającą domieszkę napowietrzającą, co jest typowym rozwiązaniem zwiększającym trwałość betonu. Zwiększenie trwałości można osiągnąć przez zastosowanie dodatków w postaci pyłu krzemionkowego lub metakaolinu. W niniejszym artykule przedstawiono porównanie betonu z metakaolinem i sproszkowanym betonek komórkowym w odniesieniu do wytrzymałości na ściskanie i mrozoodporności, wykorzystując te dodatki jako materiał zastępujący cement. Do mieszanki betonowej dodano różne ilości metakaolinu i CCP, zastępując nimi określony procent (3, 10 lub 17%) cementu. Wyniki badań pokazują pozytywny wpływ obu dodatków i pozwalają wyznaczyć dla danej mieszanki betonowej maksymalną przybliżoną wartość CCP.

Keywords: **Cellular concrete; SCM; Durability; Normal strength; Waste material.**

1. LITERATURE REVIEW

Concrete structures that are exposed to the effect of the environment have to be designed for durability as well. Normal concrete structures without any external protection system are sensitive to environmental effects, like freezing. There are different solutions that are applied when one would like to improve the durability of concrete structures. One possibility is to add air-entraining agent to the concrete mix, which produces air bubbles in the concrete mix. It was found in the literature that air-entraining agent highly increases frost resistance of concrete [2]. However, the price of air-entraining agent is high compared to the total price of concrete. Besides that, air-entraining agents have negative effect on the compressive strength of concrete and usage is not allowed in case of some application area [3]. Another solution is the application of supplementary cementitious materials (SCMs, like metakaolin and silica-fume), which lowers the porosity of the cement stone. It was shown that the lower the porosity of the cement stone, the better the durability performance of concrete is [4]. Since cement is the most expensive component of the concrete mixture partial or full replacement of it is considered as a sustainable solution towards enhancing the properties of concrete, decreasing the environmental impact of cement production and will also contribute to sustainable concrete [5]. Among of these typical SCMs, there is metakaolin, which lowers the porosity of the cement stone. When some portion of cement is replaced with metakaolin for manufacturing concrete, the compressive strength and durability (water absorption, water tightness, air permeability, chloride ion migration, freeze/thaw resistance, damage by acidic solutions, abrasion resistance) of the concrete can be improved [6–7].

Kaolinite clay (the raw material of metakaolin) can be locally available in large amounts in many countries [8]. Metakaolin thus also holds promise for use in locations, where silica-fume cannot be produced. There are many researchers who investigated the effect of metakaolin on the properties of concrete. It was found that the optimal dosage of metakaolin as additive in high performance concrete is between 0 to 25% of the cement mass [9].

By using cement supplementary materials in the aggregate, small particles are introduced in the mix, which strengthens the material and increases its durability as well [10]. It was revealed that some new waste materials have the ability to improve various properties of concrete, which make them a suitable alternative of the traditional SCMs [5 & 11].

As it was shown in the previous paper of present authors, a waste material that proved to be advantageous is cellular concrete powder (CCP) which is the result of the cutting process of cellular concrete bricks [1 & 12]. Another solution which can be applied to increase durability is the decrease of water to cement ratio of the concrete mix.

2. PRELIMINARIES

Present paper relies on a previous research of the authors [1], where the effect of different waste materials was discussed on the durability of normal strength concrete. Among those materials, the cellular concrete powder showed good performance in both strength and durability as well. There CCP was added to the concrete mix additionally to the cement (10 mass% compared to the cement in the mix). CCP increased the compressive strength of the reference mix significantly (+37%) and based on a freeze–thaw resistance test, the weight loss decreased to the half. Present paper is dealing with the comparison of CCP and metakaolin as supplementary materials. Among the different kind of supplementary cementing materials (SCMs) metakaolin was chosen, because it activates more Portlandite for the pozzolanic reactions than silica fume [10]. However, the combined use of SCMs did not result in better performance neither in compressive strength, nor in durability.

3. LABORATORY EXPERIMENTS

3.1. Concrete mix design

The concrete mix applied in this research was designed to have a relatively low resistance against freezing. The aimed strength class was C25/30 in case of the reference mix, which is a typically used concrete strength class in the industry. The aggregate was normal quartz gravel with the following particle size distribution:

- **0/4 mm**: 47% (936 kg/m^3),
- **4/8 mm**: 25% (498 kg/m^3),
- and **8/16 mm**: 28% (557 kg/m^3).

The maximum aggregate size was 16 mm. The applied cement was a CEM I 42.5 N type cement (270 kg/m^3), while the water to cement ratio was 0.57 in case of the reference mix. The above described mix was used as the reference mix, in which a given amount of cement was substituted by CCP or metakaolin in the other mixes. Finally, there were six different mixes:

- Reference: reference mix, as it is described above,
- Y3: 3% of cement was substituted by CCP,
- Y10: 10% of cement was substituted by CCP,
- Y17: 17% of cement was substituted by CCP,
- MK10: 10% of cement was substituted by metakaolin,
- MK/Y 7/3: 10% of cement was substituted 7% by metakaolin and 3% by CCP.

As it can be seen in the above list, in the present research it was intended to investigate the effect of CCP with different proportions as well as the interaction of metakaolin with CCP. It is important to mention that the aggregate size of the CCP belongs to the 0/0.25 fraction, while the metakaolin does to the 0/0.018 fraction.

From the above-described mixes, 100 mm and 150 mm edge length cubes were casted and used during the laboratory experiments.

3.2. Test descriptions

The compressive strength of the mixes was determined at 28 days of age after wet curing of the 150 mm edge length specimens. The uniaxial compressive strength test was preformed by an Alpha 3-3000 S hydraulic press with 5 kN/s (static) loading rate. The test was also done on samples which were subjected to 50, 100 or 150 freezing cycles to determine their frost resistance. This type of test is typically applied to determine the frost resistance of vertical structures, like walls, pillars. The duration of a freezing cycle is 8 hours in a laboratory freezer, where after 2 hours of cooling the samples are kept on -20°C for another 2 hours, then after 2 hours of melting they are kept in 20°C (~ room temperature) for 2 hours. After the given number of cycles, compressive strength test is applied on the samples and the differences from the standard test results are observed.

Besides these the samples were subjected to freeze-thaw resistance test, which was performed based on the recommendations of the CEN/TS 12390-9:2007 standard [13]. The samples were sawn to half and the test was performed on their sawn surface. The other surfaces of the specimen were isolated and then in 5 mm thickness a test liquid (in our case 3 m% NaCl solution) was poured on the sawn surface. On the specimens in total 56 freeze-thaw cycles were applied. The freezing cycle is similar to the one previously described, but here every step lasts 6 hours instead of 2. After 7, 14, 28 and 56 cycles the samples were taken out from the freezer and the scaled material from the tested surface was removed and weighed. The higher amount of scaled material means lower resistance against freeze-thaw.

4. RESULTS AND DISCUSSION

4.1. Compressive strength test

As it can be seen in Fig. 1 the compressive strength of all mixes with supplementary material is higher, than the compressive strength of the reference mix. By applying more and more percentage of CCP the compressive strength is increasing until a given point (around 10%), after that it is decreasing. Fig. 1 shows that even the 3% of CCP is increasing the compressive strength.

At 10% of CCP content the strength increase was 34%. In the present research the maximum applied amount of CCP was 17% and until that point the compressive strength of the mix with CCP was higher than it was in case of the reference mix. It is important to see, that here the cement is substituted by a waste material, which means a significant cost reduction (in case of the higher dosages of CCP (10 and 17%)) without losing strength performance.

The highest increase was achieved by the 10% metakaolin, which increased the compressive strength of the concrete by 61%. As it can be seen it is almost the double of the strength increase reached by the 10% CCP, however, it should be considered that CCP has no production cost because it is fully a waste material. Thus, by applying CCP instead of metakaolin, the material cost of concrete and the CO_2 emission caused by the metakaolin production process can be decreased [14]. The mix that contained both CCP and metakaolin performed well, its value was between the Y10 and MK10 mixes. It means that the two materials can be mixed.

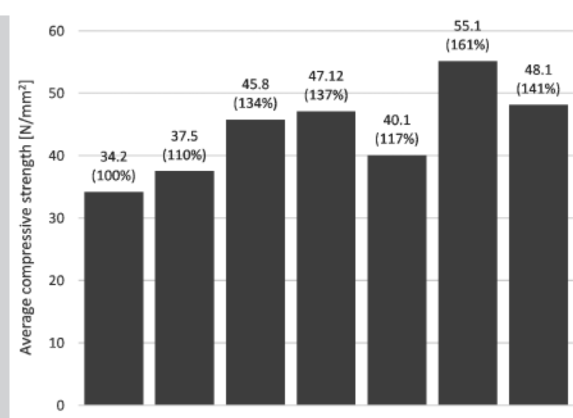

Figure 1.
Average compressive strength of the different mixes

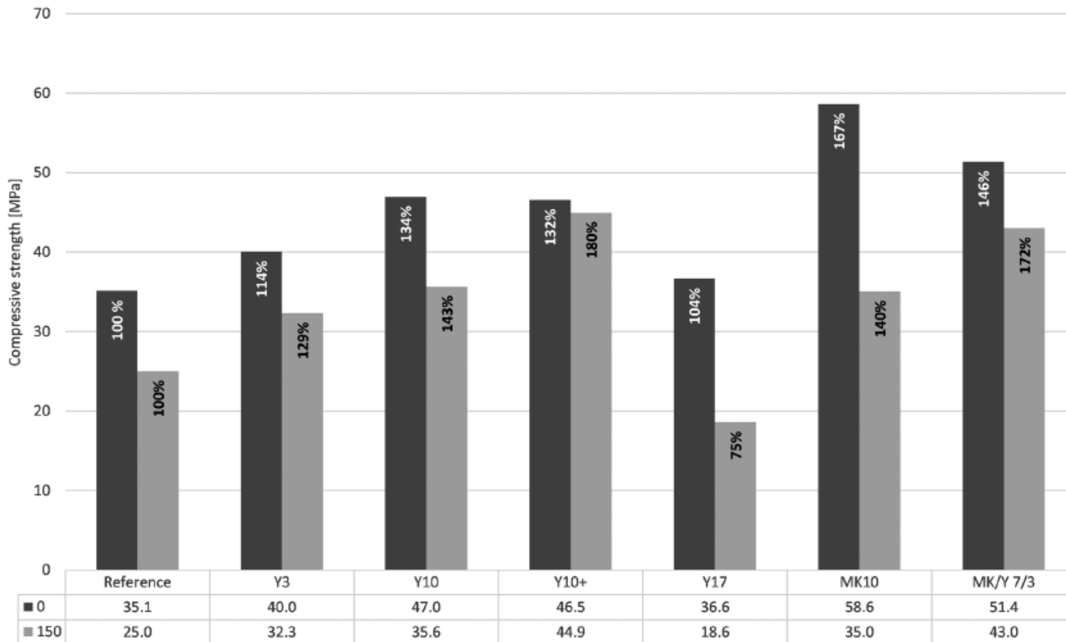

Figure 2.
Compressive strength before freezing and after 150 freeze cycles

Table 1.
Compressive strength before and after a given number of freezing cycles

Number of cycles	Compressive strength [N/mm^2]					
	R	Y3	Y10	Y17	MK10	MK/Y 7/3
0	35.1	40.0	47.0	36.6	58.6	51.4
50	32.8	33.3	39.9	33.4	45.6	43.7
100	32.8	34.9	41.3	33.0	40.1	42.3
150	25.0	32.3	35.6	18.6	35.0	43.0

4.2. Frost resistance test

In the Easter-European countries the most hazardous durability failure mode is frost damage of the structures, therefore the specimens were subjected to the two most well-known freezing tests. Tab 1. and Fig. 2. show the results of the frost resistance tests applied on our samples. In Tab. 1 the compressive strength of the samples after a given number of freezing cycles is shown. In the figure the compressive strength of the concrete can be seen before freezing (indicated by 0 number of cycles) and after 150 cycles of freezing. It is shown how large strength drop was caused by the freezing cycles.

In Fig. 2 it can be seen that the best performances had the mix with 3% of CCP and the mix where the metakaolin and the CCP were combined. In case of those two mixes the strength drop (the difference between the value belonging 0 and 150 freezing cycles) was the lowest. The figure shows that the compressive strength (after 150 cycles) of the mix with 3% of CCP was almost equal to the mix with 10% of CCP. It can be seen as well, that by applying too much of CCP (Y17) the strength drop can be even higher, than it was in case of the reference mix. After the freezing cycles the MK10 mix showed a significant strength drop and it can be seen that the mix with 10% of CCP performed slightly better, which indicates that metakaolin can be substituted by CCP.

4.3. Freeze-thaw test

The deterioration of the concrete surface was determined by freeze-thaw test and the weight loss of the samples was measured.

Fig. 3 shows the results of the freeze-thaw test, where it can be seen that the reference mix had the highest amount of scaled material, while the mix with 3% of CCP and the mix where the metakaolin and the CCP were combined, have the least. In case of this test all the mixes with any supplementary material performed better, than the reference mix, as it was planned at the mix design phase. The worst performance, among the mixes with supplementary material, was achieved by the mix with 17% of CCP. The mix with 10% of metakaolin and with 10% of CCP were between the previously mentioned mixes. By comparing these two mixes with 10% of supplementary material, it can be seen that the CCP performed bet-

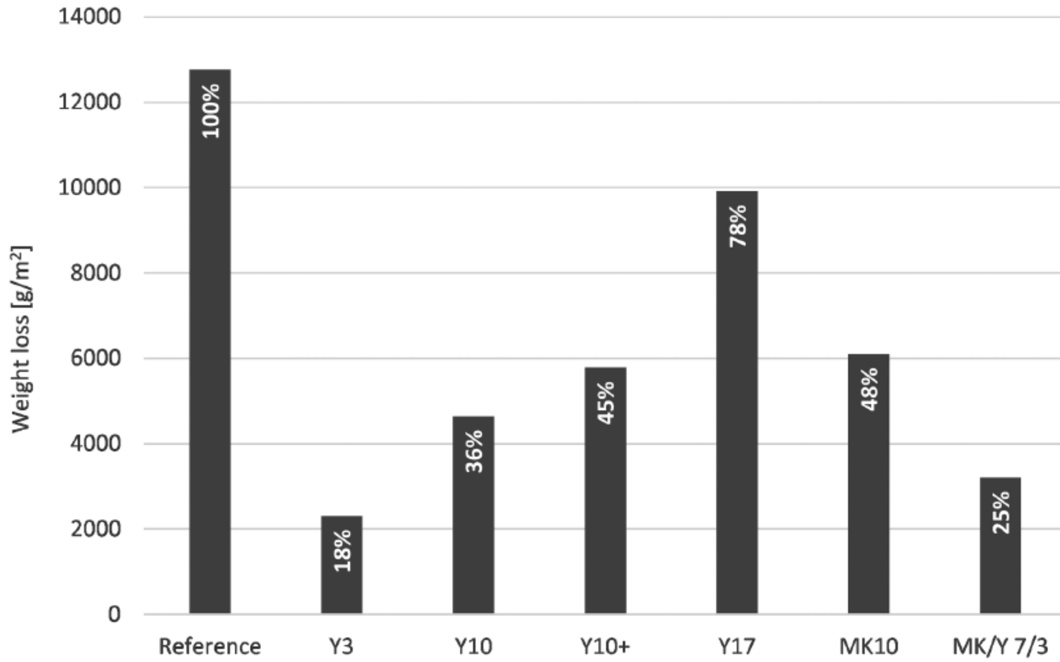

Figure 3.
Weight loss of the samples after 56 freeze-thaw cycles

ter than the metakaolin in this test too.

Despite of the decrease in the amount of the scaled material non of the mixes reached the limits of the XF2 environmental class (max 2000 g/m^2), but this was not expected from a C25/30 strength class concrete. It would be also useful to see the effect of CCP for a higher strength concrete with higher cement content as well.

5. CONCLUSIONS

In a previous study it was shown, that cellular concrete powder (CCP) as an additive can have a positive effect on both compressive strength and durability [1]. Present study introduced the application of CCP as a supplementary material (a given amount of cement was substituted by waste material), aiming to increase the durability of normal strength concrete. Compared to the other possibilities the application of a waste material can significantly decrease the cost of a concrete mix. Specimen were casted from three different mixes containing CCP, one containing metakaolin, one with both CCP and metakaolin besides a reference mix. The reference mix was designed to have low frost resistance. The specimens were subjected to compressive strength test, frost test and freeze-thaw test and the effect of the additives was observed.

Based on the test results, it can be seen that a given amount of CCP can increase the strength and durability of concrete as well (~10%), however, too much of it can cause detrimental effects, especially in compressive strength (~17%). It was also shown, that the correct amount of CCP can lead to a better performance on durability, than metakaolin, despite the fact that metakaolin increases the compressive strength more, than CCP. However, it is also important to see that CCP is completely a waste material without any need of production and preparation, which means a significant decrease in cost and in CO_2 emission as well.

The results indicate that the combination of the two investigated supplementary materials can be advantageous for many applications. The combined mix performed well on the durability tests and it increased significantly the compressive strength. It was not as advantageous in the freeze-thaw test as the mix with 3% of CCP and it did not increase the compressive strength as the 10% of metakaolin, however, it had the best performance on the frost resistance test.

Lastly, it can be proved that the correct amount of CCP can increase both the strength and the durability of normal concrete, without highly influencing the cost of the material.

6. FUTURE STUDIES

As a continuation of the present research, the authors are intending to widen the investigations on concretes with higher cement content and with different types of cement. Presented studies dealt with concrete mixes, which were less than 60 days old. Thus the authors are intending to investigate samples which were stored for longer time.

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